# The Absence of Superfluid Response in the Optical Conductivity of the Edge Region of Optimally Doped $Bi_2Sr_2CaCu_2O_{8+\delta}$ Crystals

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**Introduction**: The edge regions of high-$T_c$ superconductors have been probed extensively by tunneling experiments on the ac, bc and (110) faces of these materials into the ab-plane, particularly by Greene and co-workers. One particularly interesting result is the zero bias conductance peak (ZBCP) observed when tunneling on the ac or bc-faces coupled with the absence of a gap feature in the tunneling spectra. This is contrasted with the observation of a weaker ZBCP when tunneling on the (110) face with the appearance of a superconducting gap. When tunneling on the ab-plane into the c-axis, no ZBCP is observed. In this study, we extend the optical conductivity measurements to the same regions near the edges of ab-plane crystals in an effort to examine if the edge regions in the high-$T_c$ d-wave superconductors have any unusual properties that are different from the bulk.

**Methods and Materials**: Large optimally doped BSCCO single crystals are grown using a traveling-surface-floating-zone (TSFZ) method. Temperature dependent reflectance is measured in a near-normal-incidence arrangement from ~50 $cm^{-1}$ to over 16,000 $cm^{-1}$ on a Bruker IFS 66v/S. The absolute reflectivity is determined by an *in situ* evaporation technique and the optical conductivities are then determined from a Kramers-Kronig analysis.

**Results**: In **Figure 1**, the temperature dependent ab-plane conductivity data is shown for a single crystal BSCCO sample with E-vector parallel to the a-axis. Because of the high signal-to-noise ratio achieved using our *in situ* evaporation technique, two optic phonons at 477 $cm^{-1}$ and 630 $cm^{-1}$ have been observed in $\sigma_1$ and $\sigma_2$ for the first time in optical conductivity measurements on BSCCO. The superfluid response is observed in the ab-plane conductivities below $T_c$ as $\sigma_1$ decreases with temperature according to the Ferrel-Glover-Tinkham sum rule accompanied by a simultaneous increase in $\sigma_2$. In **Figure 2**, we have a set of data to show that with a coarser polishing finish (1μm diamond film) the conductivity of the bc-plane in the normal state is drastically reduced. There is a large spectral feature at 627 $cm^{-1}$ that appears as an anti-resonance dip in $\sigma_1$. In the insert of **Figure 2**(a), room temperature reflectance data is given with the E-vectors parallel to the b-axis and the c-axis on this bc-face. Strong anisotropy is observed in the reflectance curves, which leads us to conclude that there is no significant contamination by c-axis phonons in the conductivity data with E-vector parallel to b-axis. The temperature dependence of $\sigma_1$ and $\sigma_2$ is characteristically different from the ab-plane data and in particular there is no evidence of superfluid response in $\sigma_1$ or $\sigma_2$. However, the superfluid contribution to optical conductivity is measured in the surface region of the (110)-plane where the E-vector is parallel to an anti-nodal direction.

**Conclusions**: We have observed characteristically different behavior in the ac and bc-plane optical conductivities of optimally doped $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystals as compared to the (110)-plane conductivity below $T_c$. This apparent asymmetry implies that the surface region in the high-$T_c$ d-wave superconductors has unusual properties that are different from the bulk.

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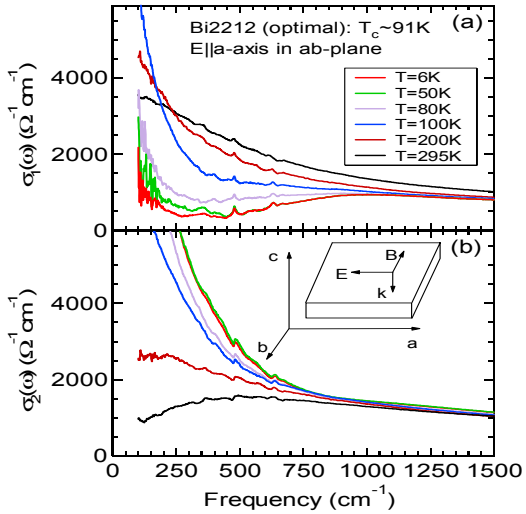


**Figure 1**. ab-plane optical conductivites of a BSCCO single crystal.

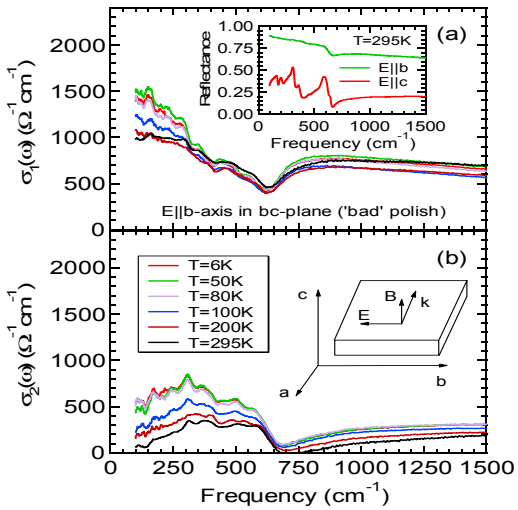


**Figure 2**. bc-plane optical conductivities of a BSCCO single crystal.